PROCESSING & CHARACTERIZATION OF JUTE/GLASS FIBER REINFORCED EPOXY BASED HYBRID COMPOSITES

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF
THE REQUIREMENTS FOR THE DEGREE OF

Master of Technology

in

Mechanical Engineering

(Specialization: Production Engineering)

By

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CERTIFICATE

This is to certify that the thesis entitled "**PROCESSING & CHARACTERIZATION OF JUTE/GLASS FIBER REINFORCED EPOXY BASED HYBRID COMPOSITES**", submitted by **Miss. Janaki Dehury** bearing **Roll no. 211ME2196** in partial fulfillment of the requirements for the award of ***Master of Technology*** in the Department of Mechanical Engineering, National Institute of Technology, Rourkela is an authentic work carried out under my supervision and guidance.

To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other university/institute for the award of any Degree or Diploma.

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Abstract

Now-a-days, the natural fibres from renewable natural resources offer the potential to act as a reinforcing material for polymer composites alternative to the use of glass, carbon and other man-made fibres. Among various fibres, jute is most widely used natural fibre due to its advantages like easy availability, low density, low production cost and satisfactory mechanical properties. For a composite material, its mechanical behaviour depends on many factors such as fibre content, orientation, types, length etc. Attempts have been made in this research work to study the effect of fibre loading and orientation on the physical, mechanical and water absorption behaviour of jute/glass fibre reinforced epoxy based hybrid composites. A hybrid composite is a combination of two or more different types of fibre in which one type of fibre balance the deficiency of another fibre. Composites of various compositions with three different fibre loading (30wt%, 40wt% and 50wt%) and three different fibre orientation (0°, 30° and 60°) are fabricated using simple hand lay-up technique. It has been observed that there is a significant effect of fibre loading and orientation on the performance of jute/glass fibre reinforced epoxy based hybrid composites. TOPSIS a multi-criteria decision making approach is also used to select the best alternative from a set of alternatives. Finally, the morphology of fractured surfaces is examined using scanning electron microscopy (SEM).

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CHAPTER 1

INTRODUCTION

INTRODUCTION

1.1Motivation and background

The development of composite materials and their related design and manufacturing technologies is one of the most important advances in the history of materials. Composites are the material used in various fields having exclusive mechanical and physical properties and are developed for particular application. Composite materials having a range of advantages over other conventional materials such as tensile strength, impact strength, flexural strengths, stiffness and fatigue characteristics. Because of their numerous advantages they are widely used in the aerospace industry, commercial mechanical engineering applications, like machine components, automobiles, combustion engines, mechanical components like drive shafts, tanks, brakes, pressure vessels and flywheels, thermal control and electronic packaging, railway coaches and aircraft structures etc.

When two or more materials with different properties are combined together, they form a composite material. Composite material comprise of strong load carrying material (known as reinforcement) imbedded with weaker materials (known as matrix).The primary functions of the matrix are to transfer stresses between the reinforcing fibres/particles and to protect them from mechanical and/or environmental damage whereas the presence of fibres/particles in a composite improves its mechanical properties like tensile strength, flexural strength, impact strength, stiffness etc.

Composites can be classified according to different criteria. Depending on the type of matrix materials, composite materials can be classified into three categories such as metal matrix composites, ceramic matrix composites and polymer matrix composites. Each type of composite material is suitable for specific applications. When the matrix material is taken as metal like aluminium, copper, it is called as metal matrix composite. These are having high ductility and strength, good fracture toughness, inter-laminar shear strength and transverse tensile strength and also having superior electrical and thermal conductivity. These materials are high dimensional stable due to low thermal expansion coefficient of matrix and withstand to a high temperature. Due to high elastic modulus of reinforcements they have very high stiffness. When the matrix material is taken as ceramic it is called as ceramic matrix composite. Ceramic material include a wide verity of inorganic materials likes bricks, pottery ,titles also include oxide, nitrides and carbides of silicon, aluminium, zirconium etc. They are normally non metallic and processed very often at high temperature. The main objective in producing ceramic matrix composites is to enhance the toughness, high strength and hardness, high temperature properties, wear resistance etc.

Polymer matrix composites consist of a polymer resin as the matrix material which filled with a variety of reinforcements. This kind of composite is used in the greatest diversity of composite applications due to its advantages such as low density, good thermal and electrical insulator, ease of fabrication, and low cost. The properties of polymer matrix composites are mainly determined by three constitutive elements such as the types of reinforcements (particles and fibres), the type of polymer, and the interface between them. Polymers are divided into two categories such as thermoplastics and thermosets. Thermoplastic are in general, ductile and tougher than thermoset materials. They are reversible and can be reshaped by application of heat and pressure. Thermoplastic molecules do not cross-link and therefore they are flexible and reformable. Generally, thermoplastics show poor creep resistance, especially at elevated temperatures, as compared to thermosets. Their lower stiffness and strength values require the use of fillers and reinforcements for structural applications. The most common materials used in thermoplastic composites are nylon, polyetheretherketone, Acetal, polyphenylene sulfide, polycarbonate, teflon, polyethylene etc. Thermoset are materials that undergo a curing process through part fabrication and once cured cannot be re-melted or reformed. Thermoset materials are brittle in nature and offer greater dimensional stability, better rigidity, and higher chemical, electrical, and solvent resistance. The most common resin materials used in thermoset composites are epoxy, polyester, phenolics, vinyl ester, and polyimides.

Based on the types of reinforcement, polymer composites can be classified as particulate reinforced polymer composite and fibre reinforced polymer composites. ***Particle reinforced composites*** also called particulate composites consisting of reinforcing material that is in the form particle. The shape of reinforcing particle may either spherical, a platelet, cubic, tetragonal, or of other regular or irregular geometry. The arrangement of the particles in the composites may be either random or preferred orientation. Generally, particles are used in composites to modify the thermal and electrical conductivities, improve performance at elevated temperatures, reduce friction, increase wear and abrasion resistance, improve machinability, increase surface hardness and reduce shrinkage.

Fibre reinforced polymer composites *also* called fibrous composites consisting of fibres as the reinforcement. Now-a-days, these composites have found applications in various areas such as automotive, marine, aerospace etc. due to their high specific stiffness and strength. Generally, fibres are the most important class of reinforcements in composite materials, as they satisfy the desired conditions and transfer strength to the matrix constituent, influencing and enhancing their desired properties. A fibre is characterized by its length being much greater as compared to its cross-sectional dimensions. The properties of matrix, fibre and its interface have greatly influencing the properties of composite materials.

Fibres in polymer composites can either synthetic/man-made fibres or natural fibres. Some commonly used synthetic fibres for composites are glass, aramid and carbon etc. There are many types of glass fibre depending upon the type of application like E-glass fibre (electrical application), C-glass (corrosive environment), S-glass (structural application, high temperature). Glass fibres are available in various forms such as continuous, chopped and woven fabrics etc. If the fibres are derived from natural resources like plants or some other living species, they are called natural-fibres.

Among all reinforcing fibres, natural fibres have gained great significance as reinforcements in polymer matrix composites. Depending upon the source of origin, natural fibres are classified as plant, animal and mineral fibres. Recently, due to the growing global energy crisis and ecological risks, natural fibres reinforced polymer composites have attracted more research interests. The main advantages of natural fibres are their availability, biodegradable, renewable, environmental friendly, low cost, low density, high specific properties,good thermal properties and enhanced the energy recovery, low energy consumption, non-abrasive nature and low cost. A great deal of work has been carried out to measure the potential of natural fibre as reinforcement in polymer such as jute, coir, bamboo ,sisal, banana and wood fibres have been reported [1]. Plant fibres are justifies their use as reinforcement for polymer composites due to their renewability with good mechanical properties. It is also observed that natural fibres are non-uniform with irregular cross sections, which make their structures quite unique and much different from man-made fibres such as glass fibres, carbon fibres etc. The properties of some of these fibres are presented in Table 1.1. These fibres are low-cost fibres with low density and high specific properties which are comparable to synthetic fibres.

Among various natural plant fibres, jute fibre has a great potential to be used as reinforcement in polymer composites. Over hundreds of years jute has been used in the applications of ropes, beds, bags etc. Jute is abundantly available in countries like India, Bangladesh, China, Nepal and Thailand. It possesses high toughness and aspect ratio in comparison to other natural fibres. Jute is a lingo-cellulosic fibre and its composites have high impact strength with moderate tensile and flexural properties compared to other fibres like coir, sisal, pineapple, banana etc. The inborn properties of jute fibre such as low density, low elongation at break and its specific stiffness and strength comparable to those of glass fibre draws the attention of the world.

Table 1.1 Physical properties of natural fibres [2]

Fibre	Tensile strength (MPa)	Young's modulus (GPa)	Elongation at break (%)	Density (g/cm^3)
Abaca	400	12	3-10	1.50
Alfa	350	22	5.80	0.89
Bagasse	290	17	----	1.25
Bamboo	140-230	11-17	-----	0.60-1.10
Banana	500	12	5.90	1.35
Coir	175	4-6	30	1.20
Cotton	287-597	5.50-12.60	7-8	1.50-1.60
Curaua	500-1150	11.80	3.70-4.30	1.40
Date palm	97-196	2.50-5.40	2-4.50	1-1.20
Flax	345-1035	27.60	2.70-3.20	1.50
Hemp	690	70	1.60	1.48
Henequen	500 70	13.20±3.10	4.80 1.10	1.20
Isora	500-600	-----	5-6	1.20-1.30
Jute	393-773	26.50	1.50-1.80	1.30
Kenaf	930	53	1.60	----
Nettle	650	38	1.70	----
Oil palm	248	3.20	25	0.7-1.55
Piassava	134-143	1.07-4.59	21.90-7.80	1.40
Pineapple	1.44	400-627	14.50	0.80-1.60
Ramie	560	24.50	2.50	1.50
Sisal	511-635	9.40-22	2.0-2.50	1.50
E-glass	3400	72	------	2.5

Composites made of the same reinforcing material system may not give better results as it undergoes different loading conditions during the service life. In order to solve this problem hybrid composites are the best solution for such applications. A hybrid composite is a combination of two or more different types of fibre in which one type of fibre balance the deficiency of another fibre. The purpose of hybridization is to construct a new material that will retain the advantages of its constituents but not their disadvantages. The concept of hybridization gives flexibility to the design engineer to tailor the material properties according to the requirements, which is one of the major advantages of composites.

The performance of fibre reinforced polymer composites is affected by many factors such as properties of the fibres, orientation of the fibres, content of the fibres, properties of the matrix, fibre-matrix interfaces etc. Increase in volume content of reinforcements can increase the strength and stiffness of a composite to a point. If the volume content of reinforcements is too high then there will not be enough matrix to keep them separate, and they can become tangled. The mechanical properties of fibre reinforced composites are affected by the elastic and strength properties of the matrix, the fibres and the fibre-matrix bond which govern the stress transfer. Similarly, a crucial parameter for the design with composites is the fibre orientation. The arrangement or orientation of the fibres relative to one another within the matrix can affect the performance of a composite. In order to obtain the preferred material properties for a particular application, it is important to know how the material performance changes with the fibre content and fibre orientation under given loading conditions.

The TOPSIS (technique for order performance by similarity to ideal solution) is one of the well known multi-criteria decision making (MCDM) method. This was developed by Hwang & Yoon in the year 1981. This is the process of finding the best option from all of the feasible alternatives. TOPSIS is a multiple criteria method to identify solutions from a finite set of alternatives based upon simultaneous minimization of distance from the Positive Ideal Solution (PIS) and the longest distance from the Negative Ideal Solution (NIS) [3].

TOPSIS has been applied to a number of applications, however use of this technique for selection of materials is hardly been reported in the literature.

The present research work thus is undertaken to study the processing, characterization and mechanical behaviour of jute/glass fibre reinforced epoxy based hybrid composites. The effect of fibre loading and orientation on the mechanical and water absorption properties are investigated. Further, with the help of micrographs, the fracture behavior of the composite was analyzed.The specific objectives of this work are clearly outlined in the next chapter.

1.2 Thesis Outline

The remainder of this thesis is organized as follows:

Chapter 2: This chapter includes a survey of the past research already available involving the issues of interest. It presents the research works on the hybrid composites and the effect of various parameters on the performance of composites studied by various investigators.

Chapter 3: This chapter includes a description of the raw materials, fabrication technique and the test procedures used.

Chapter 4: This chapter represents the physical, mechanical and water absorption behavior of the composites under study.

Chapter 5: This chapter provides a summary of the findings outlines specific conclusions drawn from the current research work and suggests ideas and directions for future research.

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CHAPTER 2

LITRETURE REVIEW

LITRETURE REVIEW

This chapter includes a survey of the past research already available involving the issues of interest. It presents the research works on the hybrid composites and the effect of various parameters on the performance of composites studied by various investigators. The literature review is done based in the following points:

2.1 Study on Natural Fibre Based Polymer Composites

In the recent years there is a vast growth in natural fibre based polymer composites due to its various attractive features likes biodegradability, no abrasiveness, flexibility, availability, low cost, light weight etc. Different researchers have performed various experiments to enhance the mechanical properties of natural fibre based polymer composites. Biswas et al. [4] studied the effect of length on mechanical behaviour of coir fibre reinforced epoxy composites and observed that the hardness is decreasing with the increase in fibre length up to 20 mm. A study on pulp fibre reinforced thermoplastic composite shows that while the stiffness is increased by a factor of 5.2, the strength of the composite is increased by a factor of 2.3 relative to the virgin polymer [5]. Gowda et al. [6] investigated the mechanical behaviour of jute fabric-reinforced polyester composites and found that jute fibre based composites shows better strengths than those of wood based composites. The mechanical properties of coir fibre/polyester composites were evaluated and the effect of the molding pressure on the flexural strength of the composites is studied [7]. Luo and Netravali [8] studied the tensile and flexural properties of polymer composites with different pineapple fibre content and compared them with the virgin resin. Amash and Zugenmaier [9] reported the effectiveness of cellulose fibre in improving the stiffness and reducing the damping in polypropylene cellulose composites. Dynamic mechanical behaviour of natural fibres like sisal, pineapple leaf fibre, oil palm empty fruit bunch fibre etc. in various matrices has been studied by Joseph et al. [10] and George et al.

[11]. A great deal of work has been done on various aspects of polymer composites reinforced with banana fibres [12-15]. Chawla and Bastos [16] investigated the effect of fibre volume fraction on Young's modulus, tensile strength and impact strength of untreated jute fibres in unsaturated polyester resin. Schneider and Karmaker [17] studied the mechanical behaviour of jute and kenaf fibre based polypropylene composites and reported that jute fibre provides better mechanical properties than kenaf fibre. A systematic study on the properties of henequen fibre and pointed out that these fibres have mechanical properties suitable for reinforcement in thermoplastic resins by Cazaurang et al. [18]. Shinichi et al. [19] have studied the effects of the volume fraction and length on flexural properties of kenaf and bagasse fibres based composites. The mechanical behaviour of unidirectional hemp fibre reinforced epoxy composites is studied by Hepworth et al. [20]. Sapuan and Leenie [21] investigated the tensile and flexural behaviour of musaceae/epoxy composites. Pavithran et al. [22] studied the fracture energies for sisal, pineapple, banana and coconut fibre reinforced polyester composites and reported that, except for the coconut fibre, increasing fibre toughness was accompanied by increasing fracture energy of the composites. Harriette et al. [23] investigated the mechanical properties of flax/polypropylene composites. Tobias [24] analysed the influence of fibre length and fibre content in banana fibre reinforced epoxy composites and reported that the impact strength increased with higher fibre content and lower fibre length. Santulli [25] investigated the post-impact behaviour of plain-woven jute/polyester composites subjected to low velocity impact and reported that the impact performance of these composites is poor.

2.2 Study on Synthetic Fibre Based Polymer Composites

A great deal of work has been done by many researchers on synthetic fibre based polymer composites. Huang et al. [26] studied on effect of water absorption on the mechanical properties of glass/polyester composites. It was concluded that the breaking strength and tensile stress of the composites decreased gradually with increased water immersion time because the weakening of bonding between fibre and matrix. Ota et al. [27] studied on the combined effect of injection temperature and fibre content on the properties of polypropylene-glass fibre composites observed that the melting flow index of the composites depend upon fibre content, fibre length distributions. The tensile strength and elastic modulus was increased with increasing in fibre contents. Jansons et al. [28] studied on the effect of water absorption, elevated temperatures and fatigue on the mechanical properties of carbon-fibre-reinforced epoxy composites. Kutty and Nando [29] studied the effect of processing parameters on the mechanical properties of short Kevlar aramid fibre-thermoplastic polyurethane composite and observed that processing parameters like nip gap, friction ratio and mill roll temperature have extreme influence on the fibre orientation and hence on the mechanical properties of short Kevlar aramid fibre-thermoplastic polyurethane composite. Yuan et al. [30] studied reinforcing effects of modified Kevlar fibre on the mechanical properties of wood-flour/polypropylene composites and observed that the addition of kelvar Fibre improved the mechanical properties of Wood Flour/Polypropylene composites. Wang et al. [31] studied the mechanical properties of fibre glass and kevlar woven fabric reinforced composites and observed that mechanical behaviour depends strongly upon the fibre types. Cho et al. [32] studied the mechanical behaviour of carbon fibre/epoxy composites and found that the composites reinforced with nano particles improved mechanical properties such as enhanced compressive strength and in-plane shear properties. Chauhan et al. [33] studied on the effect of fibre loading on mechanical properties, friction and wear behaviour of vinyl ester composites under dry and water lubricated conditions and reported that the density of composite specimens is affected marginally by increasing the fibre content.

2.3 Study on Hybrid Fibre Based Polymer Composites

The composites obtained by incorporation of two or more fibres within a single matrix are called as hybrid or hybrid composites. Hybrid fibre composites may be the combination of two or more different natural fibres or it may be the combination of natural or synthetic fibres. The conventional material such as glass, carbon and boron fibres are quite expensive and the use of fibre like carbon or boron is justified only in aerospace application [34]. Therefore it is meaningful to explore the possibility of using cheaper materials such as natural fibre as reinforcement. Various aspects of hybrid fibre based polymer composites has studied by various investigators [34-54]. Jawaid et al.[35] studied the mechanical behaviour of hybrid composites based on jute and oil palm fibre. It has been found that the use of hybrid system was effective in increasing the tensile and dynamic mechanical properties of the oil palm-epoxy composite because of enhanced fibre/matrix interface bonding. Verma et al. [36] examined the mechanical properties of glass/jute hybrid composites. The jute fabrics were modified by treatment with different chemicals. It has been observed that titanate treatment of jute fabric results in enhanced performance characteristics and mechanical properties of hybrid composites. Ashmed et al. [37] investigated the elastic properties and notch sensitivity of untreated woven jute and jute-glass fabric reinforced polyester hybrid composites, analytically and experimentally. The jute composites exhibited higher notch sensitivity than jute–glass hybrid composites. Dixit et al. [38] reported a remarkable improvement in the tensile and flexural properties of hybrid composites compared to the un-hybrid composites. It was also found that the hybrid composite offers better water absorption resistance. Ahmed et al. [39] experimentally investigated the effect of stacking sequence on mechanical properties of woven jute and glass fabric reinforced polyester hybrid composites. The layering sequence has larger effect on the flexural and inter-laminar shear properties than tensile properties. On comparing the overall properties of the laminates it was concluded that the hybrid laminates with two extreme glass plies on both side has the optimum combination with a good balance between the properties and the cost. Thew and Liao [40] informed that mechanical properties of bamboo/glass fibre reinforced hybrid composites depends on fibre length, fibre weight ratio and adhesion characteristics between the matrix and the fibre. Experimental investigation carried out by Mishra et al. [41] depicts that addition of quite small amount of glass fibre to the pineapple leaf fibre and sisal fibre-reinforced polyester matrix improves the mechanical properties of the resulting composites. The study also reported that the water absorption tendency of composites decreased because of hybridization and treatment of biofibres. Pandya et al. [42] found that on placing glass fabric layers in the exterior and carbon fabric layers in the interior of the hybrid composites gives higher tensile strength and ultimate tensile strain than hybrid composites with carbon fabric layers in the exterior and glass fabric layers in the interior. Sreekala et al. [43] concluded that incorporation of small volume fraction of glass fibre in composites results in enhanced tensile and flexural properties. Velmurugan et.al [44] studied the tensile, shear, impact and flexural properties of the palmyra/glass fibre hybrid composites. The properties of the hybrid were found to be increasing continuously with the addition of glass fibre. Goud and Rao [45] found a considerable increase in the tensile, flexural, impact and hardness properties of Roystonearegia/glass fibre hybrid composites with the increase in glass fibre loading. However, the dielectric constant and electrical conductivity values decreased with increase in glass fibre loading in the hybrid composites at all frequencies. Pothan et al. [46] studied on the banana-glass hybrid composites and found layering pattern or the geometry of the composites has a profound effect on the dynamic behaviour of the composites. Thiruchitrambalam et al. [47] studied the effect of Sodium LaulrylSulphate(SLS) and alkali treatment on the mechanical properties of banana/kenaf hybrid composites. Investigation result indicates that SLS treated hybrid composites exhibit better properties than alkali treated ones. Zhong et al. [48] informed that the surface microfibrillation of sisal fibre improves the compression strength, stability, tensile strength, internal bonding strength and wear resistance of the sisal/ aramid fibre hybrid composites. Sanjeevamurthy and Srinivas [49] studied the effect of moisture absorption on the mechanical properties of the coconut coir and sisal fibre hybrid composites and compared it with the composites with dry fibres. It was found that the tensile and the flexural strength increased with increase in fibre loading of composites at dry condition. On the other hand at wet condition, the tensile and flexural strength have a high-level drop. Venkateshwaran et al. [50] reported that the incorporation of sisal fibre in banana/epoxy composites of up to 50% by weight results in enhanced mechanical properties and decreased moisture absorption property. Girisha et al. [51] found that the hybridized composite shows greater tensile strength compared to the composites with individual type of natural fibres as reinforcement.

2.4 Study on TOPSIS

TOPSIS is one of the best methods to improve the quality of decision making for ranking alternatives from multiple alternatives. This is based on multi criteria decision making technique. Various researchers have introduced TOPSIS method indifferent problems or case studies. Athawale and Chakraborty [52] presented a logical procedure to evaluate the CNC machines in terms of cost and system specifications by using TOPSIS method. Monjezi et al. [53] attempts to examine the blasting operation in the Tajareh limestone mine and select the most appropriate blasting pattern by using TOPSIS method. Khorshidi et al. [54] reported that the selection of an optimal refinement condition to attain maximum tensile properties of Al–15%Mg_2Si is a multiple attribute decision making (MADM) problem. TOPSIS and fuzzy TOPSIS methods were employed to solve the case study problem. It has been observed that the TOPSIS method is considered to be a suitable approach in solving material selection problem when precise performance ratings are available. However, when performance ratings are vague and imprecise, the fuzzy TOPSIS method is preferred. Lin et al. [55] applied Analytic Hierarchy Process (AHP) methodology to obtain the relative weights of the evaluation criteria and extension of TOPSIS is applied to rank alternatives of mobile phones. Isiklar and Buyukozkan [56] presented a framework that integrates AHP and TOPSIS methods to help designers in finding design characteristics and customer requirements, and help achieve an effective evaluation of the final design solution. Shahroudi and Rouydel [57] proposed an integrated approach of ANP-TOPSIS in selecting the best suppliers and defined the optimum order quantities among selected suppliers by using a mathematical model. Ghaseminejad et al. [58] applied Data Envelopment Analysis and TOPSIS method for solving flexible bay structure layout. An algorithm has also been developed convenient in creating initial layout, generating layout alternatives and evaluating the best answer. Ghosh [59] used AHP and TOPSIS to determine faculty performance in engineering education. The study introduces an approach to integrate AHP and TOPSIS algorithm to support teacher evaluation decision.

2.5 Objective of the work

Keeping in view of the current status of research the following objectives are set in the scope of the present research work.

1. Fabrication of a new class of epoxy based hybrid composite reinforced with bi-directional jute and glass fibres.
2. To study the influence of fibre loading and fibre orientation on physical, mechanical and water absorption behaviour of composites.
3. To study the surface morphology using SEM study.
4. To select the best alternative from a set of alternative materials using TOPSIS method.

CHAPTER 3

MATERIALS &METHODS

MATERIALS AND METHODS

This chapter describes the details of processing of the composites and the experimental procedures carried out for their characterization and tests which the composite specimens are subjected to. The raw materials used in this work are:

3.1 Materials

1. Jute fibre
2. Glass fibre
3. Epoxy
4. Hardener

3.2 Fabrication of composites

The fabrications of composite slab are carried out by conventional hand layup technique. The bi-directional jute fibre and the E-glass fibres are used as reinforcement and epoxy is taken as matrix material. E-glass fibres are obtained from Saint Gobian Ltd. The epoxy resin and the corresponding hardener are supplied by Ciba Geigy India Limited. The low temperature curing epoxy resin and hardener are mixed in a ratio of 10:1 by weight percentage. Composites of different compositions with three different fibre loading (30wt%, 40wt% and 50wt %) and three different fibre orientations (0°,$30^{\circ}$and 60°) are made. Figure 3.1a and b shows bi-directional jute fibre and glass fibre respectively. Similarly, Figure 3.2 shows jute/glass fibre reinforced epoxy hybrid composite. The detailed composition and designation of the composites are presented in Table 3.1 The cast of each composite is cured under a load of about 50 kg for 24 hours. Finally the specimens of suitable dimension are cut with the help of hack saw for characterization and testing.

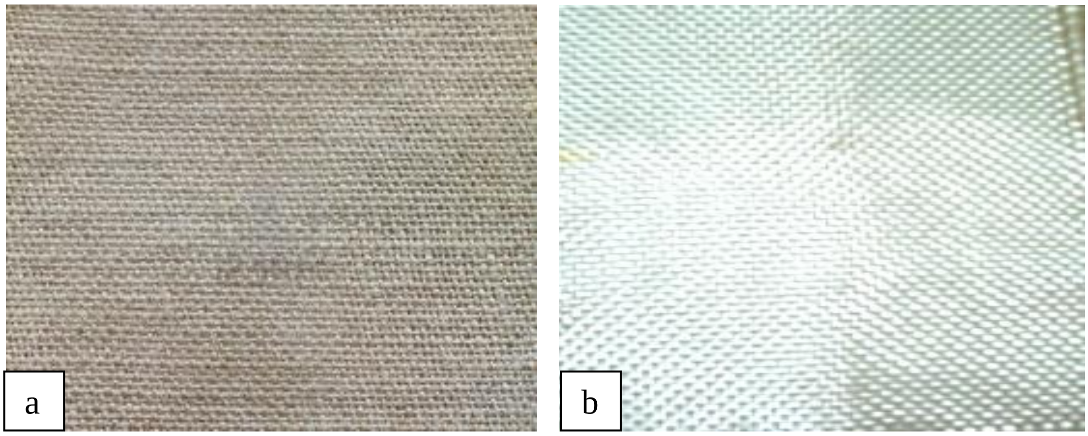


Figure 3.1 Bidirectional (a) jute fibre and (b) glass fibre

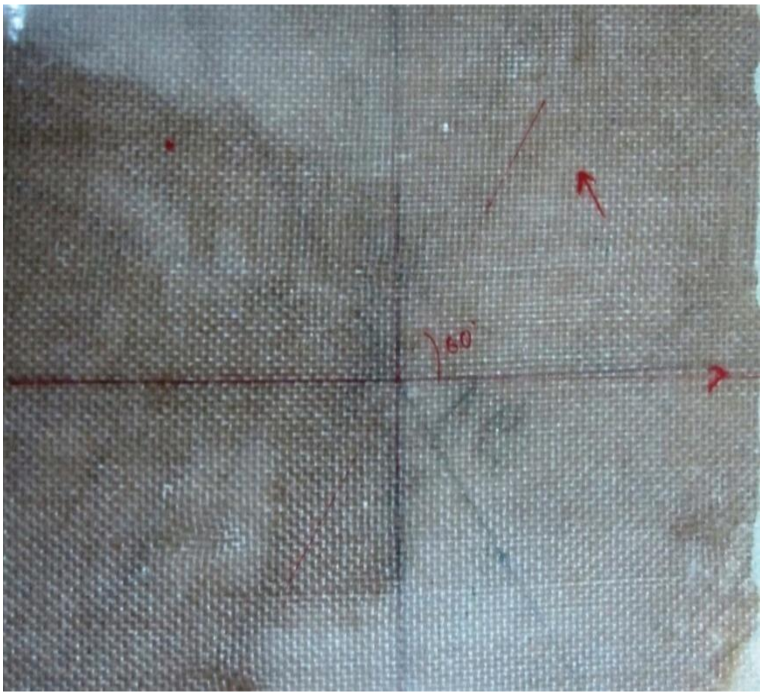


Figure 3.2 Bidirectional Jute/ Glass fibre reinforced hybrid composites

Table 3.1 Designation of Composites

Composites	Orientation (degree)	Compositions
C1	0	Epoxy (70wt%) + Glass (20 wt%) + Jute (10 wt%)
C2	0	Epoxy (60 wt%) + Glass (20 wt%) + Jute (20 wt%)
C3	0	Epoxy (50 wt%) + Glass (20 wt%) + Jute (30 wt%)
C4	30	Epoxy (70 wt%) + Glass (20 wt%) + Jute (10 wt%)
C5	30	Epoxy (60 wt%) + Glass (20 wt%) + Jute (20 wt%)
C6	30	Epoxy (50 wt%) + Glass (20 wt%) + Jute (30 wt%)
C7	60	Epoxy (70 wt%) + Glass (20 wt%) + Jute (10 wt%)
C8	60	Epoxy (60 wt%) + Glass (20 wt%) + Jute (20 wt%)
C9	60	Epoxy (50 wt%) + Glass (20 wt%) + Jute (30 wt%)

3.3 Physical and Mechanical Tests

3.3.1 Density

The theoretical density of composite material can be calculated using the formula given by Agarwal and Broutman [60].

$$\rho_{ct} = \frac{1}{\dfrac{W_f}{\rho_f} + \dfrac{W_m}{\rho_m}} \qquad \text{(Eq. 3.1)}$$

where w and ρ represent the weight fraction and density respectively. The suffix f, m and ct stands for fibre, matrix and composite material respectively. The actual density (ρ_{ce}) can be calculated experimentally by simple water immersion technique. The volume fraction of the voids (V_V) in the composite is calculated by following equation:

$$V_V = \frac{\rho_{ct} - \rho_{ce}}{\rho_{ct}} \qquad \text{(Eq. 3.2)}$$

3.3.2 Tensile Test

The tensile test generally performed on flat specimen.Tensile test of composite sample is carried out in ASTM D3039-76 test standard. In tensile test, a uniaxial load was applied through both the end. The tensile test specimen of bidirectional jute/glass fibre reinforced epoxy hybrid composites is shown in Figure 3.3. Figure 3.4a and b shows the experimental set up and loading arrangement of specimen for tensile test.

Figure 3.3 Tensile test specimen of jute/glass fibre reinforced epoxy composites

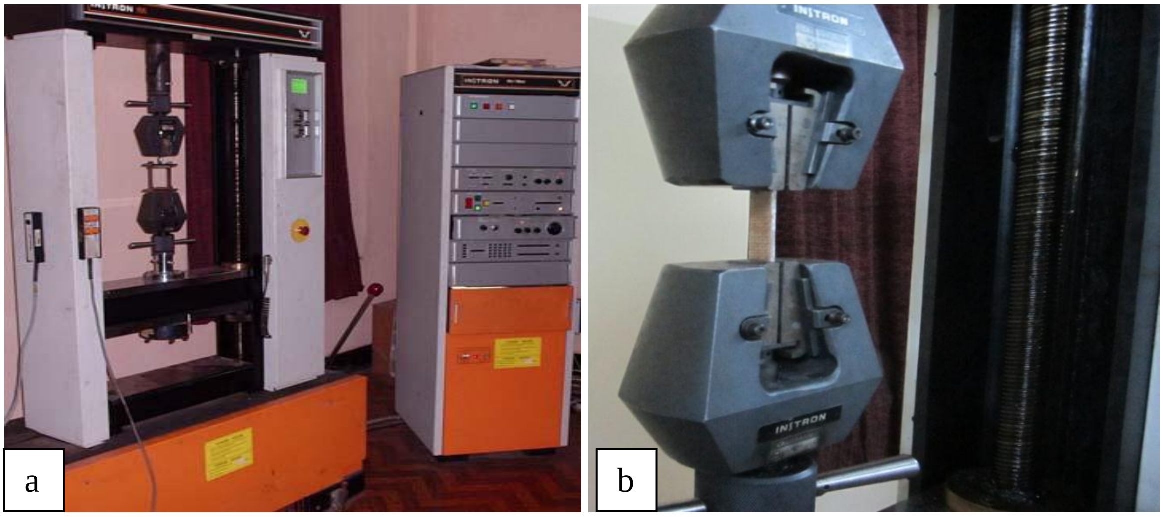


Figure 3.4(a) Experimental set up and (b) loading arrangement of specimen for tensile strength test

3.3.3 Flexural and Inter-laminar shear Test

Flexural test is to determine the capability of a material to withstand the bending before reaching the breaking point. This test is done on a three point bend test using Instron 1195.

Inter-laminar shear test is also performed on the same equipment. A span of 40 mm was taken and cross head speed was maintained at 2mm/min. Figure 3.5a and 3.5b shows the experimental set up and loading arrangement of the specimens for flexural test respectively.

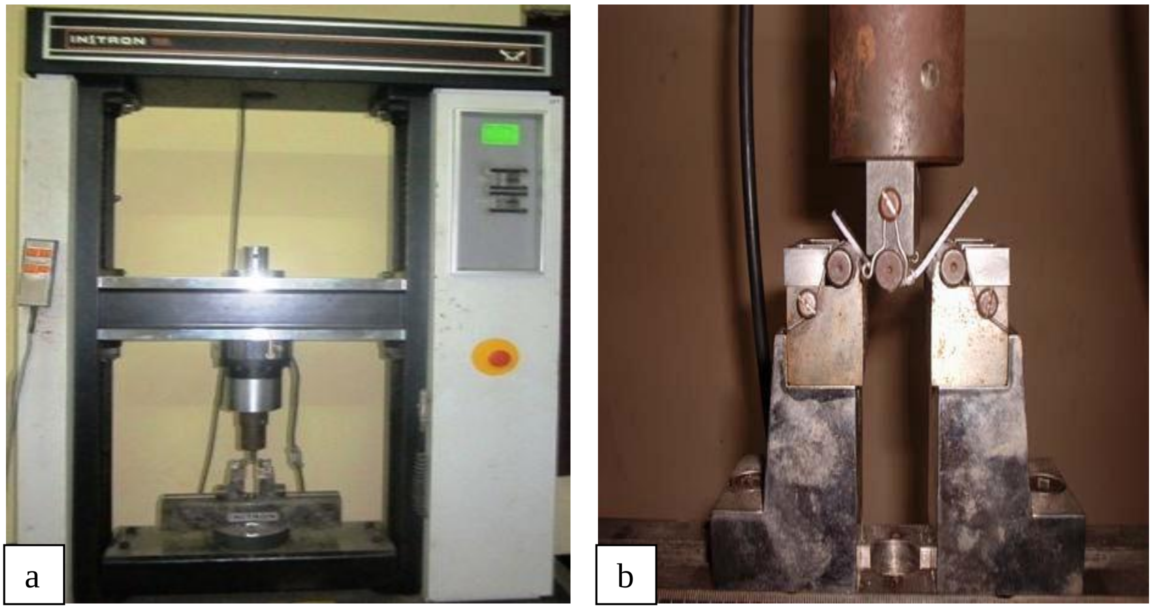


Figure 3.5 (a) Experimental set up and (b) loading arrangement of the specimens for flexural test

3.3.4 Micro-hardness Test

Leitz micro-hardness tester is used to measure the micro-hardness of composite specimens. Figure 3.6 shows the experimental set up for micro-hardness test. A diamond indenter in the form of a right pyramid of a square base of an angle 136° between opposite faces under a load P is forced into the specimen. After the removal of load, the two diagonals of the indentation (X and Y) left on the surface of the specimen are measured and their arithmetic mean L is calculated. In the present study, the load is considered as P = 24.54N and Vickers hardness number is calculated using the following equation:

$$Hv = 0.1889\frac{P}{L^2} \text{ and } L = \frac{X+Y}{2} \quad \text{(Eq. 3.3)}$$

Where P= applied load (N)

L = diagonal of square impression (mm)

X = horizontal length (mm)

Y =vertical length (mm)

Figure 3.6 Experimental set up for micro-hardness test

3.4 Scanning Electron Microscopy (SEM)

The morphological characterization of the composite surface is observed in scanning electron microscope of Model JEOL JSM-6480LV.The composite samples are cleaned properly, air-dried and are coated with 100 Å thick platinum in JEOL sputter ion coater and observed SEM at 20 kV. A thin film of platinum is vacuum evaporated onto the composite specimens in order to improve the conductivity before the micrographs are taken. The fracture surface morphology of the composite specimens after fractural test is observed by means of SEM. Figure 3.7 shows the SEM set up.

Figure 3.7 SEM Set up

3.5 Water Absorption Test

Moisture absorption studies were performed according to ASTM D 570-98 standard test method for moisture absorption of plastics. The weights of the samples were taken and then dipped them to normal water. After 24 h, the samples were taken out from the moist environment and all surface moisture was removed with the help of a clean dry cloth or tissue paper. Then the samples were reweighed to the nearest 0.001 mg within 1 min of removing them from the environment chamber. The samples were regularly weighed at 24, 48, 72, 96,120, 144, 168, 192 hrs respectively. The moisture absorption was calculated by the weight difference. The weight gain in percentage of the samples was measured at regular time intervals of time by using the following equation:

$$\%W = \frac{(W_t - W_o)}{W_o} \times 100 \qquad \text{(Eq. 3.4)}$$

Where W_t is the weight of specimen at a given immersion time and W_o is the oven-dried weight.

3.6 TOPSIS (Technique for Order Performance by Similarity to Ideal Solution)

The TOPSIS method was proposed by Hwang & Yoon in the year 1981. It is a multi criteria decision making (MCDM) technique. The basic concept of this technique is to choose the best alternative from a set of multiple attributes or goals, which has shortest distance from the ideal solution and the longest from the negative-ideal solution. The positive ideal solution is a solution that maximizes the benefit criteria and minimizes the cost criteria, whereas the negative ideal solution maximizes the cost criteria and minimizes the benefit criteria [61].Many studies have been done to introduce the TOPSIS concept to improve MCDM and solve various problems. The various steps involves are as follows [62].

Step 1: A decision matrix can be created for ranking and the MCDM problem can be expressed in matrix format as,

$$D = \begin{array}{c} \\ A_1 \\ A_2 \\ \vdots \\ A_m \end{array} \begin{array}{c} \begin{array}{cccc} C_1 & C_2 & \cdots\cdots & C_n \end{array} \\ \begin{bmatrix} x_{11} & x_{12} & \cdots\cdots & x_{1n} \\ x_{21} & x_{22} & \cdots\cdots & x_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ x_{m1} & x_{m2} & \cdots\cdots & x_{mn} \end{bmatrix} \end{array} \qquad \text{(Eq. 3.5)}$$

where A_1, A_2,...A_m are feasible alternatives out of which decision makers have to choose, C_1, C_2,.... C_n are the criteria with which alternative performance are measured, x_{ij} is the rating of alternative A_i with respect to criterion C_j, w_j is the weight of criterion C_j .

Step 2: Determine the normalized decision matrix and the normalized value n_{ij} is obtained using the formula,

$$n_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x^2{}_{ij}}} \qquad \text{(Eq. 3.6)}$$

where j= 1,2,3, ... , n

Step 3: Determine the weighted normalized decision matrix and weighted normalized value $v_{ij}$is obtained using the formula,

$$v_{ij} = w_j \times n_{ij} \qquad \text{(Eq. 3.7)}$$

where i=1,2,3. . . ., n, j=1,2,3, . . .,m and w_j is the relative weight of the j^{th} criterion or attribute,

and $\sum_{j=1}^{m} w_j = 1.$ (Eq. 3.8)

Step 4: Calculate the positive ideal solutions and negative ideal solutions respectively:

$$A^+ = \left\{ v_1^+, v_2^+, ..., v_m^+ \right\}$$
$$= \left\{ \left(\max_j v_{ij} \mid j \in \Omega_b \right), \left(\min_j v_{ij} \mid j \in \Omega_c \right) \right\} \qquad \text{(Eq. 3.9)}$$

$$A^- = \left\{ v_1^-, v_2^-, ..., v_m^- \right\}$$
$$= \left\{ \left(\min_j v_{ij} \mid j \in \Omega_b \right), \left(\max_j v_{ij} \mid j \in \Omega_c \right) \right\} \qquad \text{(Eq. 3.10)}$$

Where Ω_b and Ω_c are the sets of benefit criteria/attributes and cost criteria/attributes, respectively.

Step 5: Determine the separation measure value using the n-dimensional Euclidean distance method. The separation of each alternative from the ideal solution is given as:

$$d^+ = \sqrt{\sum_{j=1}^{n} \left(v_j^+ - v_{ij} \right)^2} \qquad \text{(Eq. 3.11)}$$

wherei = 1,2,3,. . . . .,m

Similarly, the separation from the negative-ideal solution is given as

$$d^{-} = \sqrt{\sum_{j=1}^{n} \left(v_j^{-} - v_{ij} \right)^2} \quad \text{(Eq. 3.12)}$$

Where i = 1,2,3,. . . . .,m

Step 6: Determine the relative closeness to the ideal solution and the relative closeness of the alternative Ai with respect to A^{+} is obtained as for the formula,

$$cl_i^{+} = \frac{d_i^{-}}{d_i^{+} + d_i^{-}} \quad \text{(Eq. 3.13)}$$

where i=1,2,3,. . . . . ,m

Step 7: Finally, rank the preference order. A large value of closeness coefficient cl_i^{+} indicates a good performance of the alternative A_i .The best alternative is the one with the greatest relative closeness to the ideal solution.

CHAPTER 4

RESULTS & DISCUSSIONS

RESULTS AND DISCUSSIONS

This chapter deals with the physical, mechanical and water absorption behaviour of bidirectional jute/glass fibre reinforced hybrid composite. TPOSIS a multi-criteria decision making method have been applied to rank the alternatives.

4.1 Physical and Mechanical Characteristics of Composites

4.1.1 Effect of Fibre Loading and Orientation on Density of Composites

The existence of void content in the composites significantly reduces the mechanical and physical properties of the composites. Table 4.1 shows the theoretical density, experimental density and the corresponding void content.

Table 4.1 Void fraction of hybrid composites

Composites	Theoretical Density (gm/cc)	Experimental Density (gm/cc)	Volume fraction of voids (%)
C1	1.31	1.299	0.839
C2	1.328	1.3	2.108
C3	1.345	1.298	3.494
C4	1.31	1.307	0.229
C5	1.328	1.311	1.28
C6	1.345	1.289	4.163
C7	1.31	1.297	0.992
C8	1.328	1.3077	1.528
C9	1.345	1.303	3.122

The difference in theoretical and experimental densities is mainly due to the presence of voids in the composite. Hence, it becomes essential to certain extent to determine the percentage of voids in the samples prepared. It can be seen that the void fraction in the composites increases with the fibre loading. It is observed from the table that the density of the composites significantly influenced by the fibre loading. However, density of composites influenced less by fibre orientation. The similar trend of less effect of fibre orientation on the density of composites is also observed by previous researchers [63, 64].

4.1.2 Effect of Fibre Loading and Orientation on Hardness of Composites

The variation in hardness of jute/glass hybrid composites with different fibre loading and fibre orientations are being shown in Figure 4.1.

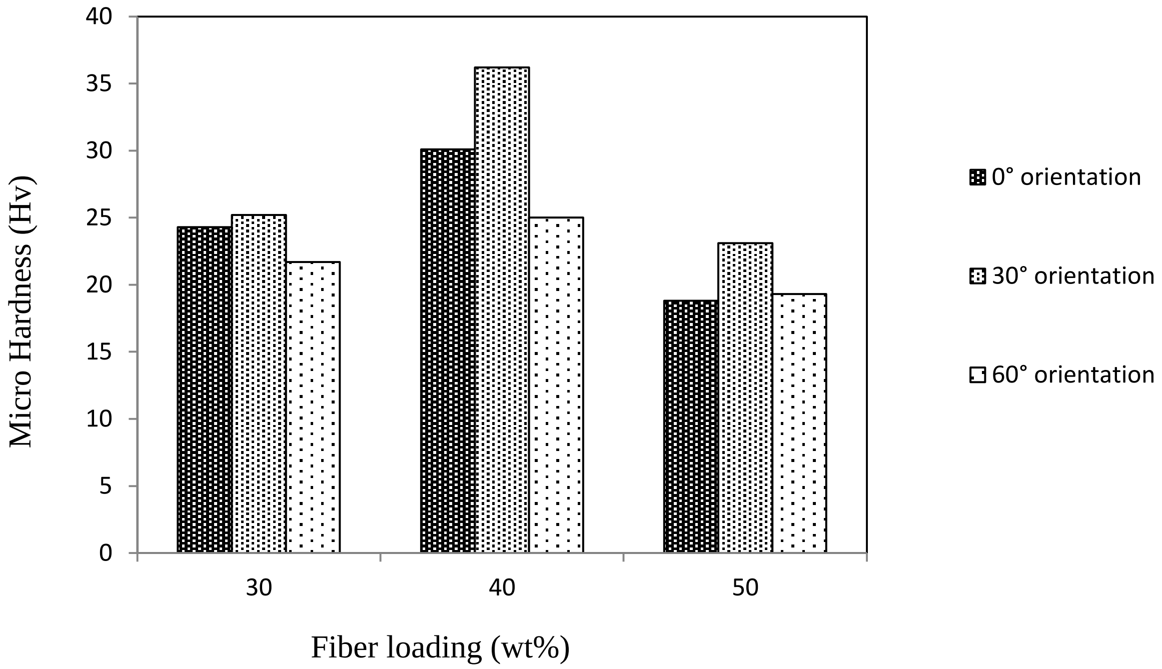


Figure 4.1 Effect of fibre loading and orientation on micro-hardness of composites

It is observed that with increase in fibre loading the micro-hardness values significantly goes on increasing up to 40 wt% fibre content, however further increase in fibre loading the value decreases irrespective of fibre orientation. Similar trend is also observed in case of fibre orientation. Composites with 40 wt% of fibre loading and 30° fibre orientation show maximum hardness value. Maximum hardness value of composites at 30° fibre orientation is also observed by previous researchers [65].

4.1.3 Effect of Fibre Loading and Orientation on Tensile Properties of Composites

The influence of fibre loading and fibre orientation on the tensile strength and tensile modulus of the composites is shown in Figure 4.2 and 4.3 respectively. It is evident from the Figure 4.2 the tensile strength of the composites decreases with increase in fibre loading and orientation. This is because of poor adhesion between fiber and matrix. The maximum tensile strength is observed for composite with 30 wt% fibre loading and 0° fibre orientations. Similar trend of maximum tensile strength at 30 wt% fibre loading and 15° fibre orientation is observed by previous researchers [65].

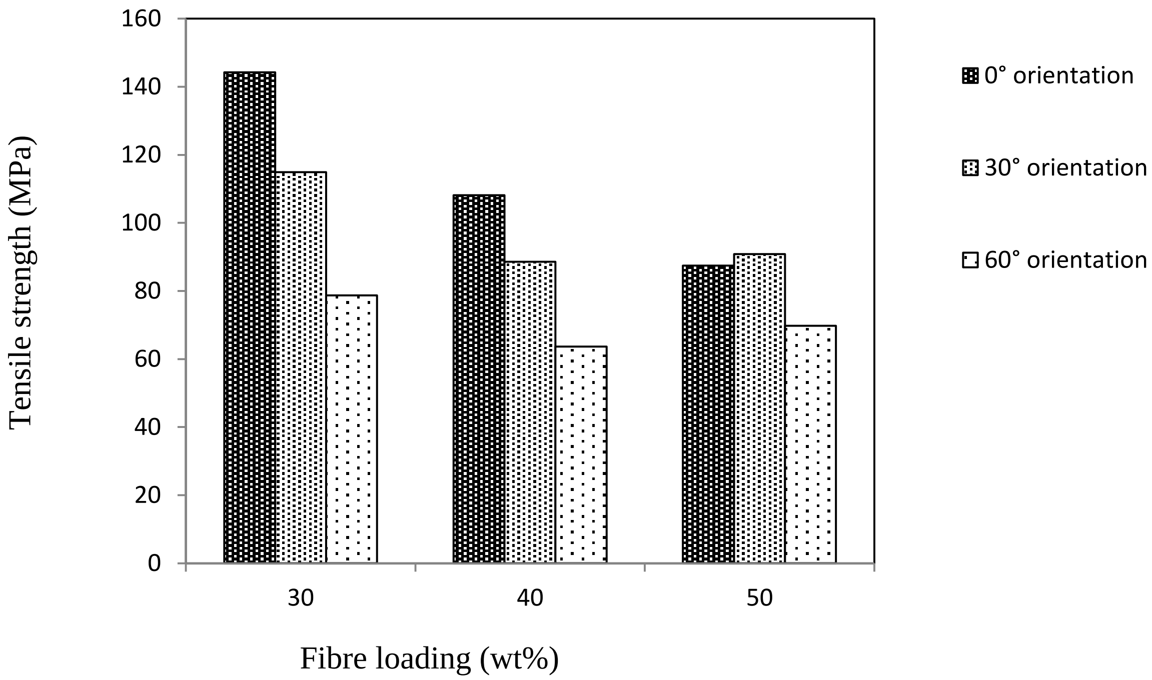


Figure 4.2 Effect of fibre loading and orientation on tensile strength of composites

Figure 4.3 shows the variation of the tensile modulus of jute-glass hybrid composites with different fibre content and orientations. The tensile modulus of composites is found to increase with increased in fiber orientation irrespective of fibre loading. On the other hand with increased in fibre loading the tensile modulus gradually goes on decreasing irrespective of fibre orientation as observed in Figure 4.3.The maximum tensile modulus is obtained for composites with 30 wt% of fibre loading and 60° fibre orientation. The possible reason of increase in tensile strength and modulus may be the proper adhesion between fiber and matrix in case of composite with 30% fiber contents.

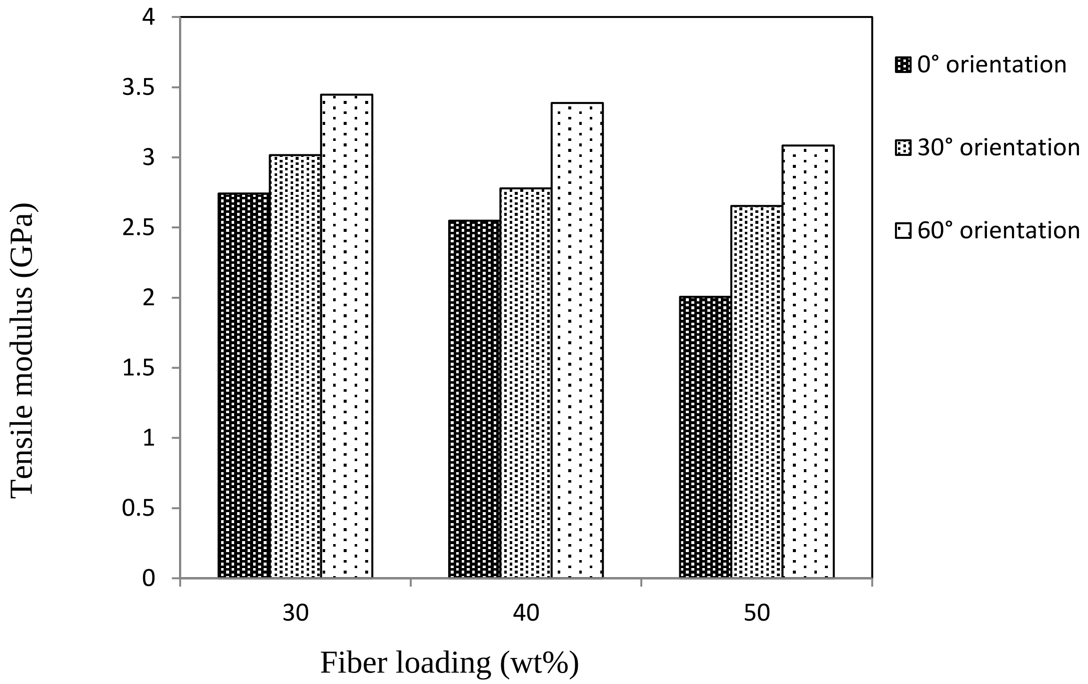


Figure 4.3 Effect of fibre loading and orientation on tensile modulus of composites

4.1.4 Effect of Fibre Loading and Orientation on Flexural Properties of Composites

The effect of fibre loading and fibre orientation on the flexural strength and modulus of composites is shown in Figure 4.4 and 4.5 respectively. It is noticeable that both fibre content and fibre orientation is having a significant effect on flexural strength. The flexural strength of composites is increased up to 40 wt% fibre loading and then decreased with the increase in fibre loading irrespective of fibre orientation. Similar trend is also observed in case of fibre orientation. The maximum flexural strength is observed for the composite with 40 wt% of fibre loading and 30° fibre orientation.

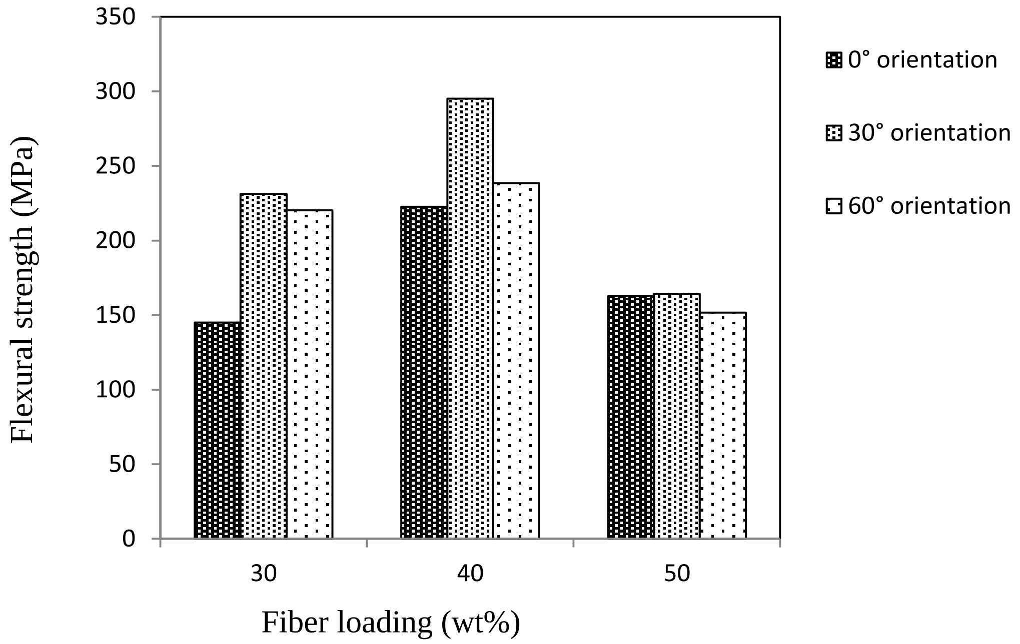


Figure 4.4 Effect of fibre loading and orientation on flexural strength of composites

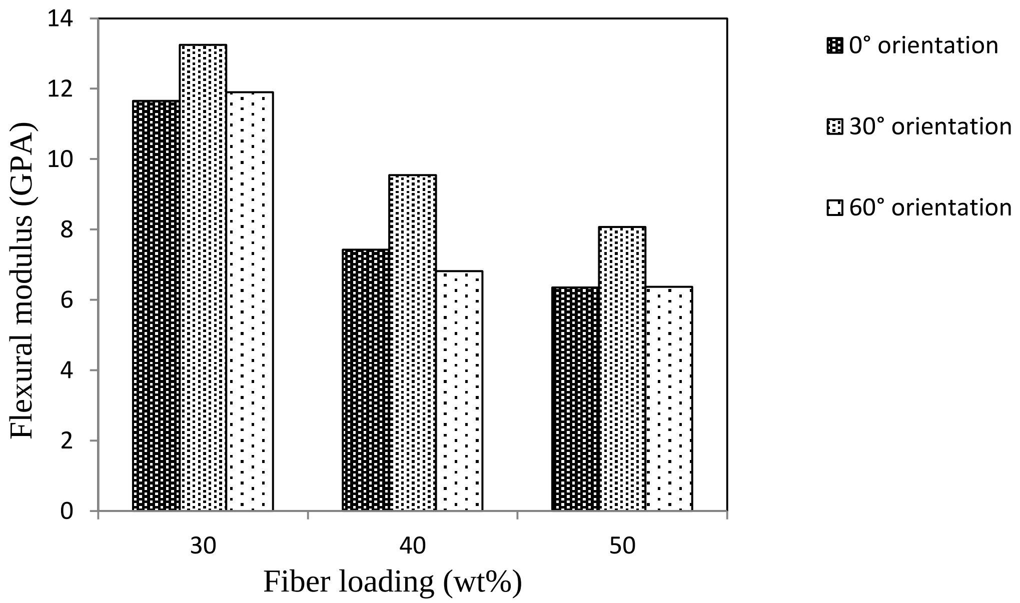


Figure 4. 5 Effect of fibre loading and orientation on flexural modulus of composites

Figure 4.5 shows the variation of the flexural modulus of composites with different fibre loading and orientations .The flexural modulus of the composite increased up to 30° fibre orientation and then decreased with increase in fibre orientation irrespective of fibre loading. Whereas according to fibre loading the maximum flexural modulus observed at 30 wt% fibre content irrespective of fibre orientation. The maximum flexural modulus of composite obtains at 30° orientation and 30 wt% fibre content.

4.1.5 Effect of Fibre Loading and Orientation on Inter-laminar Shear Strength of Composites

The variation of the inter-laminar shear strength of composites with different fibre loading and orientations is shown in Figure 4.6. It is evident from the figure that with the increase in fibre loading the inter-laminar shear strength initially goes on increasing up to 40% fibre loading then decreases. Similarly, with increase in fibre orientation the inter-laminar shear strength increased up to 30° fibre orientation then decreases. The inter-laminar strength is found to be maximum for composites with 40 wt % fibre loading and at 30° fibre orientation.

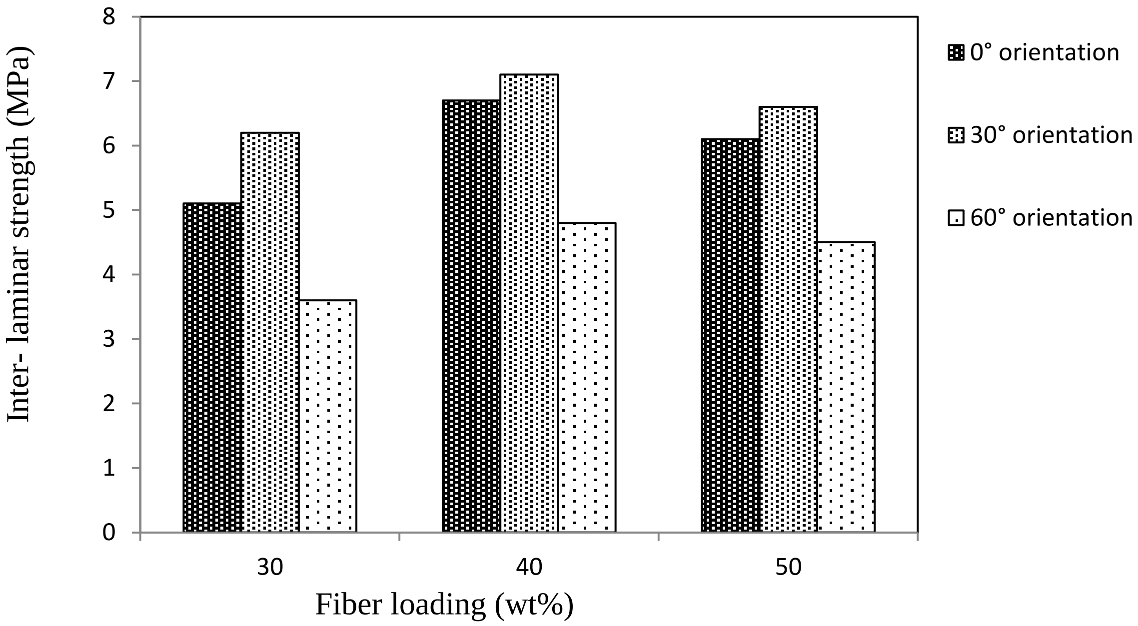
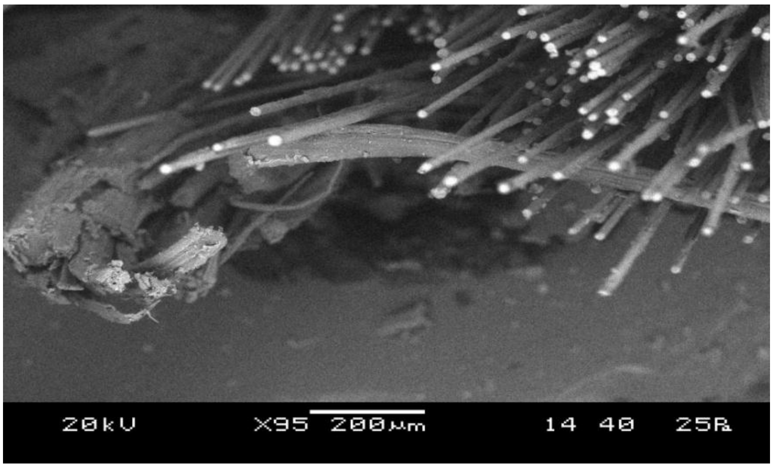


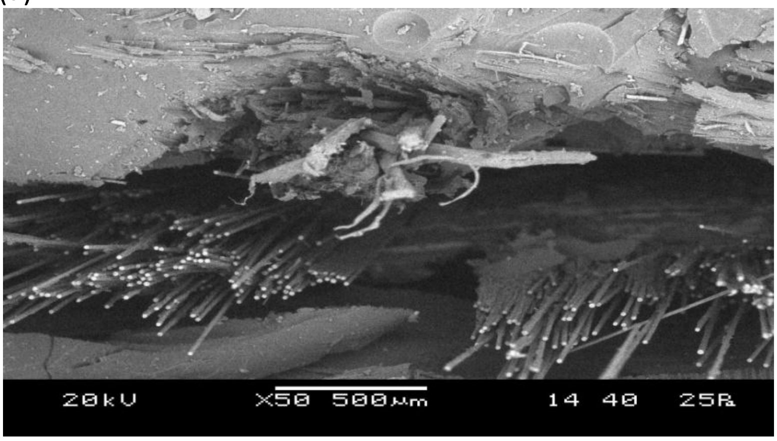
Figure 4.6 Effect of fibre loading and orientation on Inter-laminar shear strength of composites

4.2 Surface Morphology of Composites

Figure 4.7 a-c shows the fracture surfaces of jute/glass fibre reinforced epoxy composite after the flexural test under different fibre loading and orientation.



(a)



(b)

(c)

Figure 4.7 Scanning electron micrographs of jute/glass fibre reinforced epoxy composite specimens after flexural test at different fibre loading and orientation.

Figure 4.7a shows the fracture of composite specimen at 30 wt% fibre loading and 0° fibre orientation. Figure 4.7b shows the SEM image of fracture surface of composite specimen reinforced with 50wt% fibre loading at 60° fibre orientation. It can be seen from the figures that the fibres are detached from the resin surface due to poor interfacial bonding. Fracture surface of composites reinforced with 40 wt% fibre loading at 30° fibre orientation shown in Figure 4.7c. It is evident from the figure that surface without much fibre pull out is clearly visible which leads to the better compatibility of fibre and matrix.

4.3 Water Absorption Behaviour of Composites

Water absorption test is very important to determine the water absorptivity of the water absorption of the material [66]. The percentage of weight gain in various composites with time duration is shown in Figure 4.8.

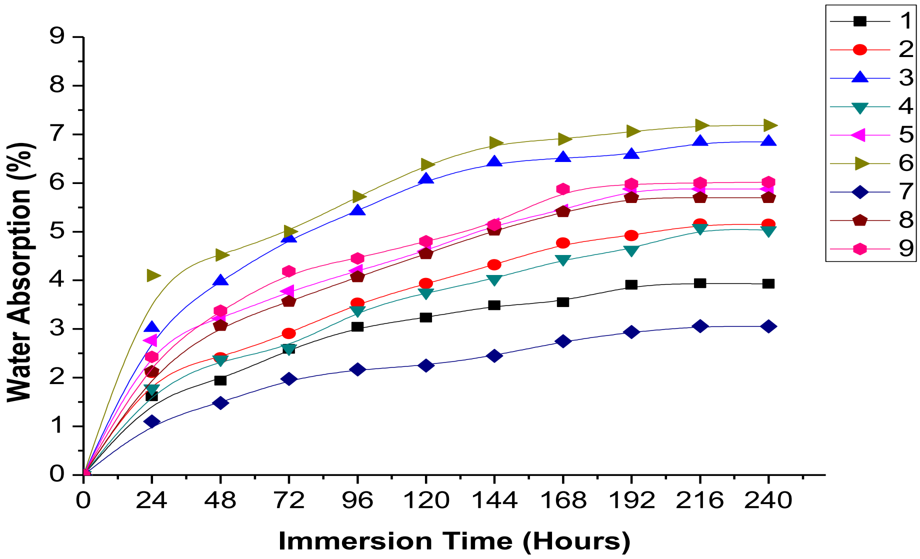


Figure 4.8 Effect of immersion time on water absorption properties of composites

It is observed from the Figure 4.8 that with increase in fibre loading the water absorption gradually increases irrespective of fibre orientation .This behaviour was expected because the water absorption of these composites is mainly due to the presence of jute fibres. There are three main reasons in the composite because of which water can reside in composite. Those are the lumen, the cell wall and the gaps between fibre and resin in the case of weak interface adhesion is found [67]. The maximum water absorption obtains at 50% fibre loading irrespective of fibre orientation. As far as effect of fibre orientation on the water absorption of composites is concerned there is not much influence is observed.

4.4 Ranking of materials using TOPSIS Method

TOPSIS method is a powerful technique for selecting the best alternatives from number possible alternatives. According to this the best alternative would be the one that is closest to the positive-ideal solution and farthest from the negative ideal solution. TOPSIS main aim is to selecting the top ranked alternative and comparing it with all ranks in this set of simulations. All the composite materials are compared based on the TIOPSIS method and ranking has been done. The decision matrix, normalization matrix, weight normalized matrix, ideal positive and ideal negative solution, separation measure, relative closeness value and ranking are tabulated in Tables 4.2,4.3,4.4,4.5,4.6 and 4.7 respectively.

Table 4.2 Decision Matrix

Composites	Tensile strength (MPa)	Flexural strength (MPa)	Inter-laminar strength (MPa)	Micro-hardness (Hv)	Density (gm/cc)	Water absorption (wt%)
C1	144.2	145.1	5.1	24.3	1.299	3.92699
C2	108.1	222.7	6.7	30.1	1.3	5.15072
C3	87.4	162.9	6.1	18.8	1.298	6.84794
C4	114.9	231.3	6.2	25.2	1.307	5.03049
C5	88.58	295.1	7.1	36.2	1.311	5.878
C6	90.78	164.4	6.6	23.1	1.289	7.1837
C7	78.65	220.3	3.6	21.7	1.297	3.0532
C8	63.65	238.46	4.8	25	1.3077	5.69818
C9	69.79	151.7	4.5	19.3	1.303	6.01991

Table 4.3 Normalization Matrix

Composites	Tensile strength (MPa)	Flexural strength (MPa)	Inter-laminar strength (MPa)	Micro-hardness (Hv)	Density (gm/cc)	Water absorption (wt%)
C1	0.496018	0.231397	0.296047	0.319146	0.33274	0.235382
C2	0.371842	0.355149	0.388924	0.395321	0.332996	0.308732
C3	0.300638	0.259784	0.354095	0.246911	0.332484	0.410462
C4	0.395232	0.368864	0.3599	0.330966	0.334789	0.301525
C5	0.304697	0.470608	0.412143	0.475435	0.335814	0.352325
C6	0.312265	0.262176	0.383119	0.303386	0.330179	0.430588
C7	0.27054	0.351322	0.208974	0.284999	0.332228	0.183007
C8	0.218943	0.380282	0.278632	0.328339	0.334969	0.341546
C9	0.240063	0.241922	0.261218	0.253478	0.333765	0.360831

Table 4.4 Weight Normalized Matrix

Composites	Tensile strength (MPa)	Flexural strength (MPa)	Inter-laminar strength (MPa)	Micro hardness (Hv)	Density (gm/cc)	Water absorption (wt%)
C1	0.082339	0.038412	0.049144	0.052978	0.055235	0.039073
C2	0.061726	0.058955	0.064561	0.065623	0.055277	0.051249
C3	0.049906	0.043124	0.05878	0.040987	0.055192	0.068137
C4	0.065609	0.061231	0.059743	0.05494	0.055575	0.050053
C5	0.05058	0.078121	0.068416	0.078922	0.055745	0.058486
C6	0.051836	0.043521	0.063598	0.050362	0.05481	0.071478
C7	0.04491	0.058319	0.03469	0.04731	0.05515	0.030379
C8	0.036345	0.063127	0.046253	0.054504	0.055605	0.056697
C9	0.039851	0.040159	0.043362	0.042077	0.055405	0.059898

Table 4.5 Ideal Positive and Ideal Negative Solution

Solution	Tensile strength (MPa)	Flexural strength (MPa)	Inter-laminar strength (MPa)	Micro-hardness (Hv)	Density (gm/cc)	Water absorption (wt%)
A^+ (ideal solution)	0.082339	0.078121	0.068416	0.078922	0.05481	0.030379
A^- (negative ideal solution)	0.036345	0.038412	0.03469	0.040987	0.055745	0.071478

Table 4.6 Separation Measure

Composites	S+	S-
C1	0.051933	0.059317
C2	0.03768	0.054542
C3	0.072349	0.028247
C4	0.040039	0.051561
C5	0.042421	0.067266
C6	0.068232	0.034504
C7	0.06269	0.046894
C8	0.064195	0.033849
C9	0.078124	0.015032

Table 4.7 Relative closeness value and ranking

Composites	Closeness factor	Ranking
C1	0.533184	4^{th}
C2	0.591424	2^{nd}
C3	0.280799	8^{th}
C4	0.562889	3^{rd}
C5	0.613257	1^{st}
C6	0.335852	7^{th}
C7	0.42793	5^{th}
C8	0.345242	6^{th}
C9	0.16136	9^{th}

Finally the ranking of different composite based on their properties is being shown in the Figure 4.9. It has been observed that ranking of composite materials are as follows: Rank 1(C5), Rank 2 (C2), Rank 3 (C4), Rank 2 (C1), Rank 5 (C7), Rank 6 (C8), Rank 7 (C6), Rank 8 (C3) and Rank 9 (C9).

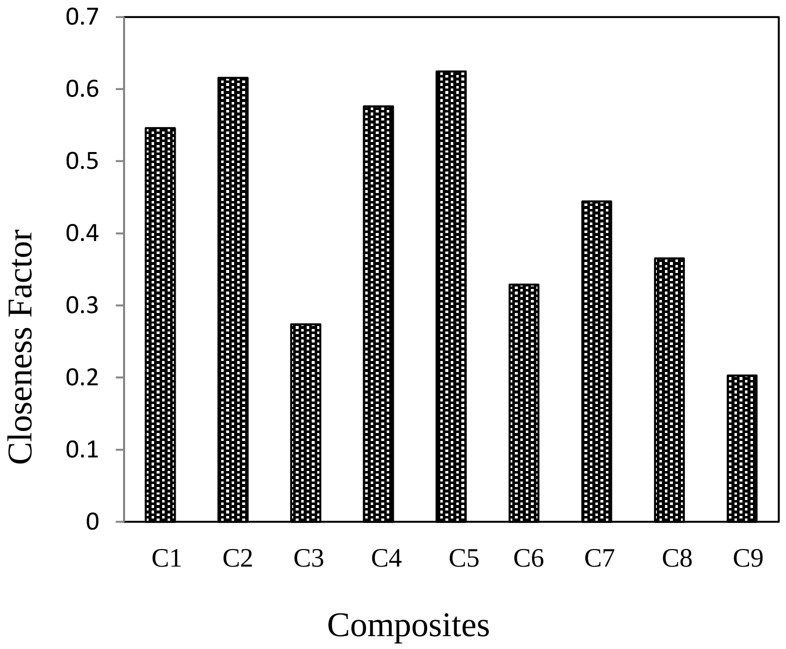


Figure 4.9 Ranking of the composites

CHAPTER 5

CONCLUSIONS

CONCLUSIONS

The experimental study on the effect of fibre loading and orientation on physical, mechanical and water absorption behaviour of jute/glass fibre reinforced epoxy based hybrid composites leads to the following conclusions:

1. The successful fabrications of a new class of epoxy based hybrid composites reinforced with jute and glass fibre have been done. The present investigation revealed that fibre loading and orientation significantly influences the different properties of composites. The maximum hardness, flexural strength and inter-laminar shear strength is obtained for composites reinforced with 40 wt% fibre loading and at 30° fibre orientation. However, the maximum tensile strength is observed for composites with 30 wt% of fibre loading and at 0° fibre orientation.
2. SEM images of the fracture surfaces of composites after the flexural test shows that the increase in mechanical properties of composites at 40 wt% fibre loading at 30° fibre orientation is due to the better interfacial bonding between fibre and matrix.
3. The water absorption rate gradually increases with increase in fibre loading irrespective of fibre orientation. The maximum water absorption is obtained for composites with 50 wt% fibre loading irrespective of fibre orientation. As far as effect of fibre orientation on the water absorption of composites is concerned there is not much influence is observed.
4. TOPSIS method is used to select a best alternative from a set of alternatives. It has been observed that ranking of composite materials are as follows: Rank 1(C5), Rank 2 (C2), Rank 3 (C4), Rank 2 (C1), Rank 5 (C7), Rank 6 (C8), Rank 7 (C6), Rank 8 (C3) and Rank 9 (C9).

5.1 Scope for future work

There is a wide scope for future scholars to explore the current research area. The present work can be further extended to study other aspects of composites like use of other natural fibres and evaluation of their dynamic mechanical, thermal, tribological properties and the experimental results can be similarly be analyzed.

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